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Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 1995

by

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Abstract

A review of physical oceanographic conditions on the continental shelves and adjacent offshore areas off the Scotian Shelf and Gulf of Maine during 1995 is presented. At Boothbay Harbor and St. Andrews, sea surface temperatures were above normal throughout most of the year whereas at Halifax they were below normal. In the deep basins and channels on the Scotian Shelf and in the Gulf of Maine, the lower layer waters remained approximately 1-2°C warmer than normal although at Cabot Strait temperatures fell relative to last year to near normal values. These warm temperatures reflect the presence of warm slope water. In the 50-100 m layer over most of the Scotian Shelf and in the deep waters in the northeast, temperatures remained colder-than-normal by 1°C. These cold conditions have persisted since at least the mid-1980s and although they appear to be moderating in the southwestern Scotian Shelf there is little evidence of moderating temperatures in the northeast.

Résumé

Un examen des conditions océanographiques physiques sur les plateaux continentaux et dans les zones hauturières adjacentes au large de la plate-forme Scotian et du golfe du Maine, en 1995, est présenté. À Boothbay Harbor et à St. Andrews, les températures à la surface de la mer ont été supérieures à la normale pendant presque toute l'année tandis qu'à Halifax, elles étaient inférieures à la normale. Dans les bassins profonds et les chenaux du plateau néo-écossais et dans le golfe du Maine, la température des eaux de la couche inférieure était supérieure d'environ 1 à 2° C à la normale mais dans le détroit de Cabot, les températures ont baissé par rapport à l'an dernier pour revenir à des valeurs près de la normale. Ces températures douces sont causées par la présence des eaux de pente chaudes. Dans la couche de 50 à 100 m recouvrant la majeure partie de la plate-forme Scotian et dans les eaux profondes au nord-est, les températures sont demeurées inférieures à la normale d'un degré C. Les conditions demeurent froides depuis au moins le milieu des années 1980 et même si les températures semblent s'adoucir dans le secteur sud-ouest du plateau néo-écossais, on ne constate aucun adoucissement des températures au nord-est.

Introduction

This paper describes temperature and salinity characteristics during 1995 in the waters on the Scotian Shelf and in the Gulf of Maine (Fig. 1). The data are derived from coastal sea surface stations, long-term monitoring stations or transects, annual groundfish surveys, ships-of-opportunity and research vessels. Most of the data are available in the BIO historical temperature and salinity (AFAP) database which was updated five times in 1995 from the data archive at the Marine Environmental Data Service (MEDS) in Ottawa. Oceanographic conditions are expressed within the paper as monthly or annual anomalies, defined as deviations from the long-term means. Where possible, the latter have been standardized to a 30-yr base period in accordance with the convention of the World Meteorological Organization. More detailed information on the oceanographic conditions in 1995 during the annual groundfish surveys are provided in Page et al. (1996). Meteorological and sea ice information for the region during 1995 are described in Drinkwater et al. (1996). Information on the positions of the shelf/slope front and the north wall of the Gulf Stream, usually found in our annual review, were unavailable at the time of writing.

Coastal Sea Surface Temperatures

Monthly averages of sea surface temperature (SST) are available from Halifax Harbour in Nova Scotia, St. Andrews in New Brunswick, and Boothbay Harbor in Maine. The monthly mean temperature anomalies relative to the 1961-90 long-term averages at each of the sites for 1994 and 1995 are shown in Fig. 2.

The dominant feature at Boothbay Harbor and St. Andrews was the above normal temperatures throughout all or most of the year. This continued a trend of warm temperatures that began in June of 1994. The 1995 anomalies equalled or exceeded one standard deviation (based upon the years 1961-90) in 8 and 3 months at Boothbay Harbor and St. Andrews, respectively. The maximum monthly anomaly was over 2.3°C in January at Boothbay while at St. Andrews it was 1.3°C in October. In contrast, sea surface temperature anomalies at Halifax were predominantly negative. Only in August and September were above normal anomalies observed. The largest negative anomalies occurred during the spring, reaching -1.6°C in June. The cold temperatures in Halifax continues the anomaly pattern established last year.

Time series of the annual anomalies show that since the late 1980s, the trends at the Gulf of Maine and Bay of Fundy sites have generally been on the increase whereas those along the Atlantic coast of Nova Scotia have been decreasing (Fig. 2). Annual SST mean temperatures for 1995 were 9.8°C (1.3°C above normal) at Boothbay Harbor, 7.8°C (0.6°C above normal) at St. Andrews, and 7.2°C (0.6°C below normal) at Halifax. These represent a rise in temperature over last year at Boothbay (by 0.5°C) and St. Andrews (0.1°C) but similar to last year at Halifax. At Boothbay the temperature is the highest since the early 1950s whereas at Halifax they are nearly as cold as the mid-1960s.

Prince 5

Temperature and salinity measurements, taken once per month since 1924 at Prince 5, a station off St. Andrews, New Brunswick, near the entrance to the Bay of Fundy, is the longest continuously operating hydrographic monitoring site in eastern Canada. Single observations per month, especially in the surface layers in the spring or summer may not necessarily be representative of the "average" conditions for the month and therefore the interpretation of the anomalies must be viewed with some caution. No significance should be placed on any individual anomaly but persistent anomaly features are likely to be real. The general vertical similarity in temperatures over the 90 m water column is due to the strong tidal mixing within the Bay of Fundy.

In 1995, monthly observations ranged from a minimum of less than 2°C in the upper half of the water column in February to a maximum of over 12°C in the near surface waters in September (Fig. 3). Monthly temperature anomalies were generally positive with maximum values >1°C in February and towards the end of the year (Fig. 3). The predominance of positive temperature anomalies match similar conditions in the SSTs at St. Andrews and Boothbay Harbor (Fig. 2). The annual temperature anomalies in 1995 were 0.2°C and 0.6°C at the surface and near bottom (90 m), respectively (Fig. 4). These are cooler than last year but well above 1992 and 1993 values. At both depths, the maximum annual temperature occurred in the early 1950s and the minima in the mid-1960s.

Salinities at Prince 5 during 1995 oscillated between saltier and fresher-than-normal (Fig. 3). The lowest salinities (<30.5 psu) occurred during May resulting in an anomaly of -0.5 psu in the surface waters. This was short-lived, however, and may not have been truly representative of the monthly mean. A second salinity minima of 31 (anomaly of -1) was observed in November in the near surface waters. The highest salinities (>32.5 psu) appeared near bottom in January and again in the autumn. These produced near-normal to slightly saltier-than-normal anomalies. Time series show that the annual salinity anomalies in 1995 fell by 0.3-0.4 from last year, to a near normal value at 90 m and below normal at the surface (Fig. 5).

Gulf of Maine Temperature Transect

The Northeast Fisheries Science Center in Narragansett, Rhode Island, has collected expendable bythythermograph (XBT) data approximately monthly from ships-of-opportunity since the late 1970s along a transect in the Gulf of Maine from Massachusetts Bay to the western Scotian Shelf as part of their continuous plankton recorder program. We grouped the available data into 10 equally spaced boxes along the transect, then averaged any data within these by month at standard depths. In 1995, data were collected in 11 months (none in August) with 4 to 9 sites occupied per month and an average of 7.

Data from January and July 1995 are shown together with the site locations (center of the boxes) in Figs. 6 and 7, respectively. January data (none available at sites 1 and 10) show the

coldest waters off Nova Scotia and the warmest in the deep (150-200 m) layers of Georges Basin (site 7). The latter originate in the offshore slope waters and are transported onto the shelf through the Northeast Channel by cross-shelf exchange processes. To the east on the Scotian Shelf, the waters were colder-than-normal, typically by 0.5-1.5°C, whereas in the central and western regions anomalies were generally warm, reaching upwards of 2°C in the deeper waters of the Gulf. In July, the Gulf was strongly stratified with maximum temperatures > 16°C in the surface waters of the central Gulf. The coldest waters, in contrast to January, were at intermediate depths in the western Gulf. This is often referred to as the "cool pool" and is formed principally by *in situ* winter cooling. Water off Nova Scotia (sites 8-9) was again colder-than-normal while warm temperature anomalies occupied the deep layers (> 100 m). The "cool pool" waters were slightly colder-than-normal while off the northern tip of Massachusetts Bay, the near surface waters were very cold (anomaly colder than -6°C). The latter was perhaps due to wind-induced upwelling. The warm deep water observed in January and July was a persistent feature throughout the remainder of 1995. The cold waters off Nova Scotia were also typical in 1995, with below normal temperatures in 7 of the 11 months when measurements were taken. In three of the remaining 4 months, temperatures were near normal and only in September were temperatures above normal. The near surface and intermediate depth temperatures, however, showed more spatial and temporal variability than the bottom waters. In the central Gulf within the upper 100 m, below normal temperatures appeared in 7 of the 11 months, while in the west they appeared in only 5 months.

Deep Emerald Basin Temperatures

Petrie and Drinkwater (1993) assembled a time series of monthly temperature data from 1946 to 1988 at multiple depths in Emerald Basin in the center of the Scotian Shelf. They showed that there was high temperature variance at low frequencies (decadal periods). This signal was more visible at depth (below 75 m) where the low-frequency variance was higher and there was less high-frequency (year-to-year) variability. High coherence at low frequencies was found throughout the water column as well as horizontally from the mid-Atlantic Bight to the Laurentian Channel, although year-to-year differences between locations were observed. Temperature anomalies at 250 m have been used as a representative index.

In 1995, temperature measurements in Emerald Basin were obtained in six separate months with values at 250 m ranging from 10.9 to 9.3°C. This produced monthly anomalies of 1.0-2.5°C above normal (Fig. 8). The long-term annual average is 8.5°C and the monthly means range from 7.9°C to 9.4°C. The anomalies were generally representative of conditions throughout the water column including the near surface waters. An exception was February when temperatures in the top 75 m were 2-3°C below normal. The generally warm temperatures, especially in the deep waters, during the last three years began with an intrusion of warm slope water late in 1991 or early 1992.

Other Scotian Shelf and Gulf of Maine Temperatures

Drinkwater and Trites (1987) tabulated monthly mean conditions for irregularly shaped areas on the Scotian Shelf and in the eastern Gulf of Maine that generally corresponded to topographic features such as banks and basins (Fig. 9). From data collected in 1995, we have produced monthly mean conditions at standard depths (averaging any data within the month anywhere within these areas) and compared them to the long-term averages (1961-90). Unfortunately, data are not available for each month at each area and in some areas the monthly means are based upon only one profile. Thus care again must be taken in interpreting these data and little weight given to any individual mean.

This analysis was first undertaken during the 1993 review (Drinkwater and Pettipas 1994). It identified several important features. First, the temperatures in the upper 30 m tended to vary greatly from month to month, due to the greater influence of atmospheric heating and cooling. Second, at intermediate depths of 50 m to approximately 150 m, temperatures had declined steadily from approximately the mid-1980s into the 1990s. On Lurcher Shoals off Yarmouth, on the offshore banks and in the northeastern Scotian Shelf the temperature minimum in this period approached or matched the minimum observed during the very cold period of the 1960s. The third main feature was the presence of anomalously warm slope water off the shelf and in the deep basins such as Emerald on the Scotian Shelf and Georges in the Gulf of Maine. This warm deep water appeared to influence the intermediate depth waters above the basins as their anomalies were generally warmer than elsewhere on the shelves.

During 1994, we examined the spatial extent of the cooling of the intermediate layer waters during the late 1980s and into the 1990s (Drinkwater et al. 1995). The cold water was traced through the Gulf of Maine from southern Nova Scotia, along the coast of Maine and into the western Gulf. Similar cooling occurred at approximately the same time at Station 27 off St. John's, Newfoundland, off southern Newfoundland on St. Pierre Bank (Colbourne 1995) and in the cold intermediate layer (CIL) waters in the Gulf of St. Lawrence (Gilbert and Pettigrew 1996). The 1994 data indicated warming of the intermediate layers in the Gulf of Maine but continued cold water on much of the Scotian Shelf.

Monthly mean temperature anomaly profiles during 1995 show that the general patterns identified by Drinkwater and Pettipas (1994) have continued. Cold conditions prevailed in the northeast Scotian Shelf (Fig. 10), along the Atlantic coast of Nova Scotia to Lurcher Shoals (Fig. 11) and on some of the outer Banks, such as Western, Sable and LaHave. Warmer-than-normal conditions were observed in Emerald and Georges Basins and, in most months that observations were taken, on some of the other outer banks, such as Browns, Emerald and Banquereau. The warm conditions on these banks are believed to be due to the influence of slope waters. On Sydney Bight, temperatures oscillated between above and below normal through the year. The cold conditions at Lurcher and warm in the deep sections of Georges Basin were seen earlier from the XBT data (Fig. 6 and 7). Also, the warm waters in Emerald Basin are consistent with the temperature data shown in Fig. 8.

The time series of monthly mean temperature data at 50 m for Lurcher and 100 m at Misaine Bank show that the long-term trend has been dominated by warm periods in the 1950s and mid-1970s to mid-1980s and cool periods in the 1960s and since the mid-1980s. These conditions are generally representative of the average conditions throughout the water column at Lurcher because of the strong tidal mixing and below approximately 50 m in the northeastern Scotian Shelf region. These cold temperatures appear to be moderating at Lurcher but not in the northeast at Misaine.

Temperatures during the Summer Ground Fish Survey

The best temperature coverage over the entire Scotian Shelf occurs during the annual groundfish survey, usually in July. During the 1995 survey, 30-40 XBTs were taken in the western Scotian Shelf and Lurcher areas in addition to the CTD profiles obtained at the trawl sites. These data were combined and temperatures were interpolated onto a 0.2 by 0.2 degree latitude-longitude grid using an objective analysis procedure known as optimal estimation. The interpolation method used the 15 "nearest neighbours" within a radius of 30 km. The data were also interpolated in the vertical, 15 m in the upper 30 m and 25 m below that. Temperatures at 0, 50, 100 m and near bottom were optimally estimated. Maximum depths were limited to 300 m as we were primarily interested in the temperatures over the shelf. In addition, the 1961-90 means for July were estimated onto the same grid in order to calculate temperature anomalies.

Temperatures in 1995 at the surface varied from 9-16°C with the coldest temperatures in the Bay of Fundy and off Lurcher due to strong tidal mixing, and the warmest temperatures off Sydney Bight, originating from the Magdalen Shallows in the Gulf of St. Lawrence (Fig. 12a). Other features are the cooler waters in the Northeast Scotian Shelf and along the coast of Nova Scotia and warm temperatures near Emerald Basin. At 50 m the coldest temperatures were in the northeast and the warmest along the continental shelf through the presence of slope waters (Fig. 12b). Note the cold waters covering most of the northeastern Scotian Shelf and off the "south shore" of the Atlantic coast of Nova Scotia. Warm waters penetrated into the central shelf regions over Sable Island Bank and into Emerald Basin. The 100 m temperatures show a pattern similar to that for 50 m but with temperatures slightly higher, especially over the Emerald Basin region (Fig. 12c). Bottom temperatures show several standard features (Fig. 12d). First is the large contrast between the northeast and central Scotian Shelf. In the northeast, bottom temperatures were generally cold with minima less than 1°C in the Misaine Bank region. Cool waters were also found along the Atlantic coast of Nova Scotia, especial to the south. Temperatures in Emerald Basin exceeded 9°C as did those in the central Gulf of Maine. Relatively high temperatures also were found along the continental slope and the upper reaches of the Bay of Fundy.

Temperature anomalies at the 3 depth levels and near bottom, all show similar patterns (Fig. 13). To the northeast extending from the Laurentian Channel to Sable and Western Banks, temperatures were below normal. Maximum values were -3°C in the surface waters between Chedabucto Bay and Sable Island. Elsewhere through the water column, anomalies were

typically -0.5 to over -1°C. The southwestern end of the Shelf was also cold with surface anomalies of -2°C and deeper anomalies similar to that in the northeast. In contrast, anomalies in the central Scotian Shelf region were above normal except at the surface. The largest positive anomalies were near bottom and had magnitudes of 1-2°C. This is consistent with the 250 m temperatures in Emerald Basin (Fig. 8).

Cabot Strait Deep Temperatures

Bugden (1991) investigated the long-term temperature variability in the deep waters (200-300 m average) of the Laurentian Channel in the Gulf of St. Lawrence from data collected between the late 1940s to 1988. The variability was dominated by low-frequency (decadal) fluctuations with no discernible seasonal cycle. A phase lag was observed along the major axis of the channel such that events propagated from the mouth towards the St. Lawrence Estuary on time scales of several years. The updated time series based primarily upon ice forecast cruises conducted by the Bedford Institute in November-December show that temperatures declined steadily between 1988 and 1991 to their lowest value since the late 1960s (near 4.5°C and an anomaly of exceeding -0.9°C). In 1992, however, temperatures rose dramatically to 5.3°C (an anomaly of 0.1°C) and to over 6.0°C (anomaly of 0.6°C) in 1993. In 1994 temperatures dropped although anomalies remained positive. Temperatures again fell in 1995 towards near normal by November (Fig. 14). This decrease in temperature contrasts with that for the deep waters in Emerald Basin where temperatures remained high.

Summary

In 1995, cold conditions existed in the bottom waters and throughout much of the water column on the northeastern Scotian Shelf, inshore along the Atlantic coast of Nova Scotia and off southwestern Nova Scotia. This continued a pattern established in the middle of the 1980s. They are believed related advection of cold water from the Gulf of St. Lawrence and off the Newfoundland Shelf and to a lesser extent *in situ* cooling during the winter although the relative importance has not yet been established. In contrast to these cool conditions, the waters in the central Scotian Shelf over Emerald Basin and along the continental slope, were warmer-than-normal. These conditions have persisted since 1992 and reflect the presence of warm slope water offshore. In the Gulf of Maine, temperatures were predominantly warmer-than-normal which is believed to be due to the influx of slope water into the region through the Northeast Channel.

Outlook for 1996

The cold waters on the northeastern Scotian Shelf will remain cold but may begin to warm. This is based upon the milder winter in the Gulf of St. Lawrence in 1996 then in recent years and the assumed importance of winter wixing in the Gulf and subsequent advection onto the Scotian Shelf. Off southwest Nova Scotia where moderation of the cold water has already begun, this should continue due in large part to mixing with warm, deep waters in the Gulf of

Maine. Warm temperatures in the deep waters of the Gulf of Maine and in Emerald Basin are expected to remain so as the temperature in the slope waters continues to be above normal.

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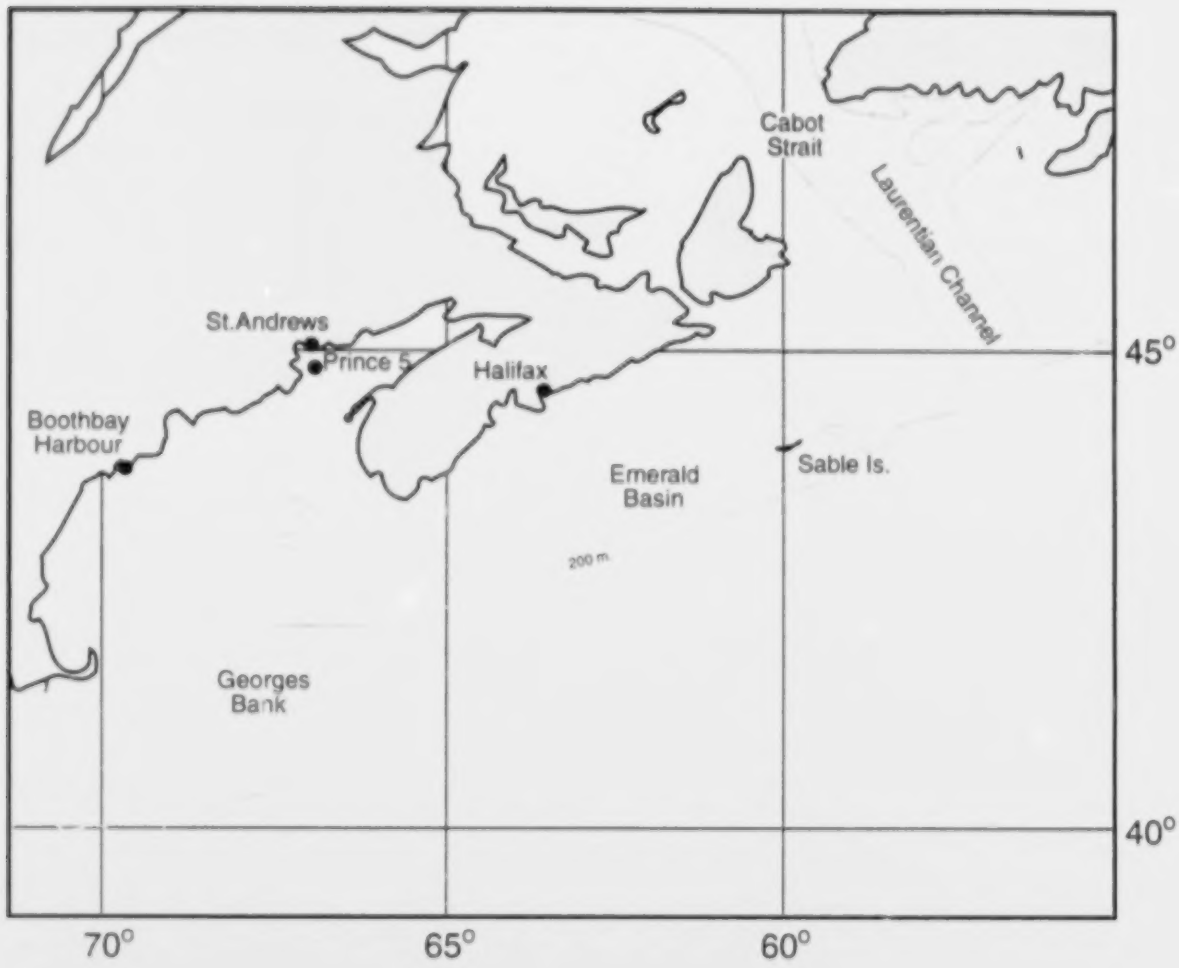


Fig. 1. The Scotian Shelf and the Gulf of Maine showing sea surface temperature stations, Prince 5 and topographic features.

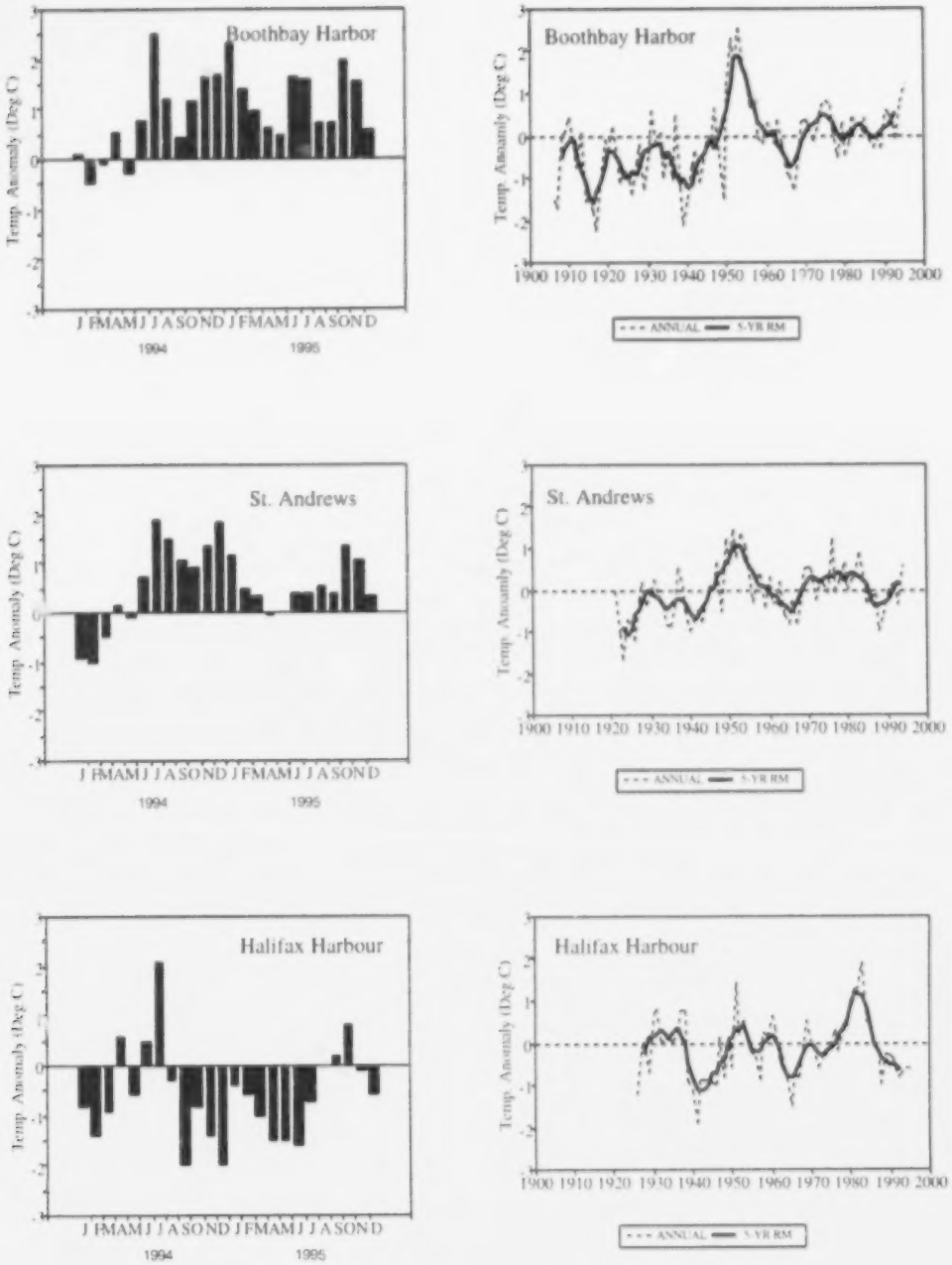


Fig. 2. The monthly sea surface temperature anomalies during 1994 and 1995 (left) and the annual temperature anomalies and their 5-year running means (right) for Boothbay Harbor, St. Andrews and Halifax. Anomalies are relative to 1961-90 means.

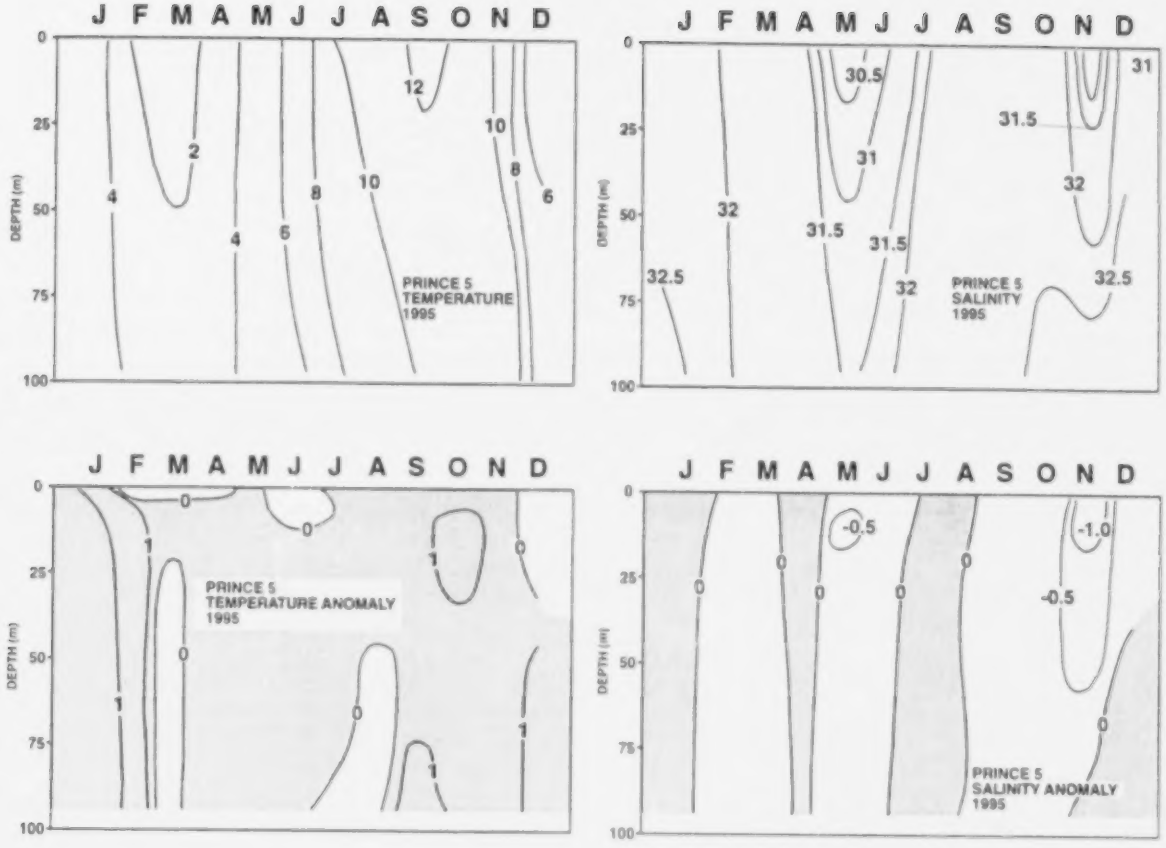


Fig. 3. Monthly temperatures and salinities and their anomalies at Prince 5 as a function of depth during 1995 relative to the 1961-90 means. Shaded areas are positive anomalies.

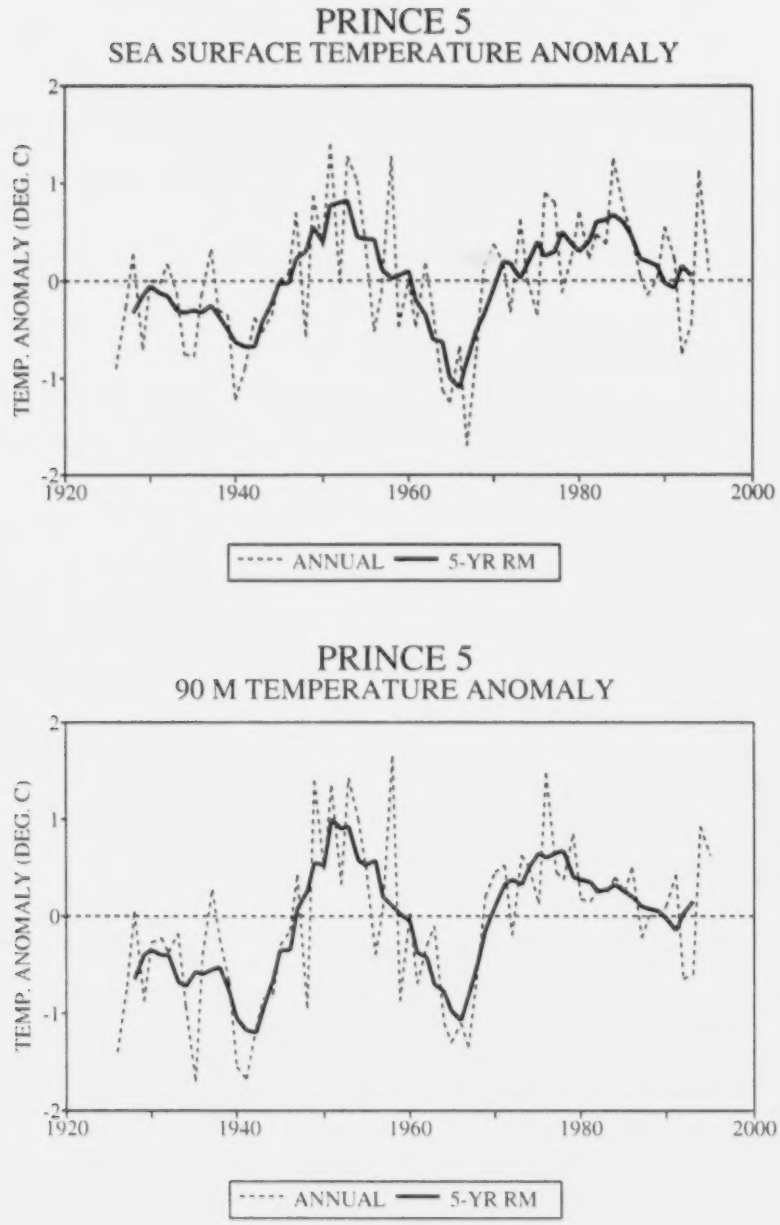


Fig. 4. The annual means and the 5-year running means of the temperature anomalies for Prince 5, 0 (top) and 90 m (bottom).

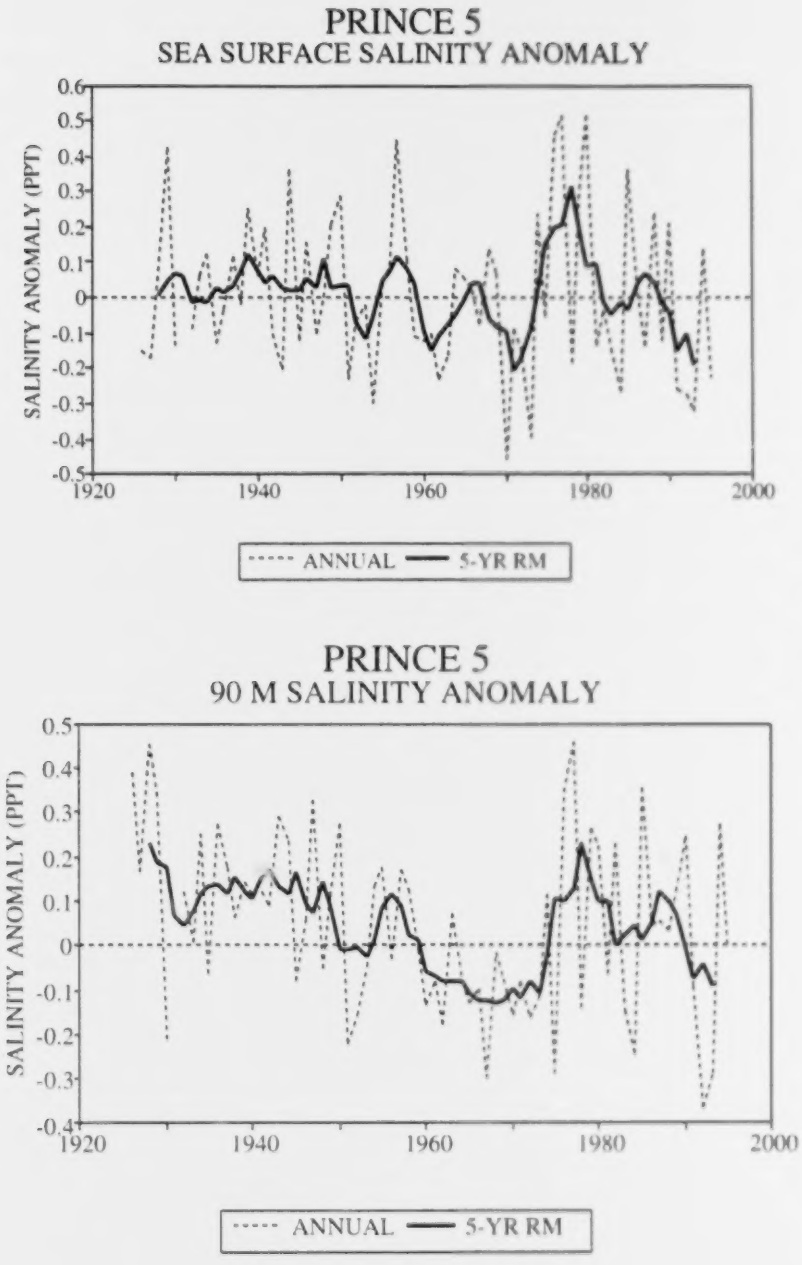


Fig. 5. The annual means and 5-year running means of the salinity anomalies for Prince 5, 0 (top) and 90 m (bottom).

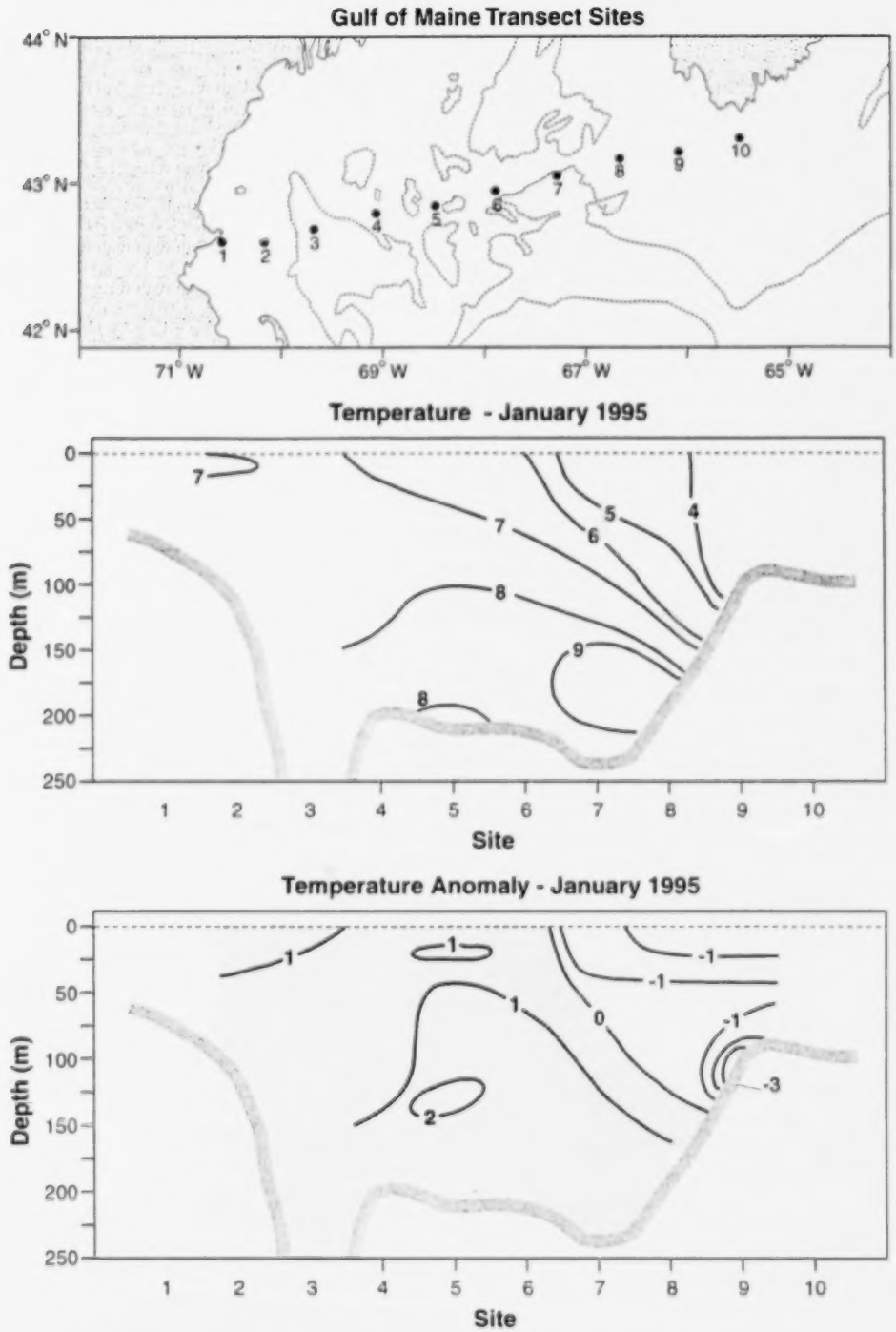


Fig. 6. The temperature (middle) and temperature anomalies (bottom) in degrees Celsius along a XBT transect (top) across the Gulf of Maine during January 1995.

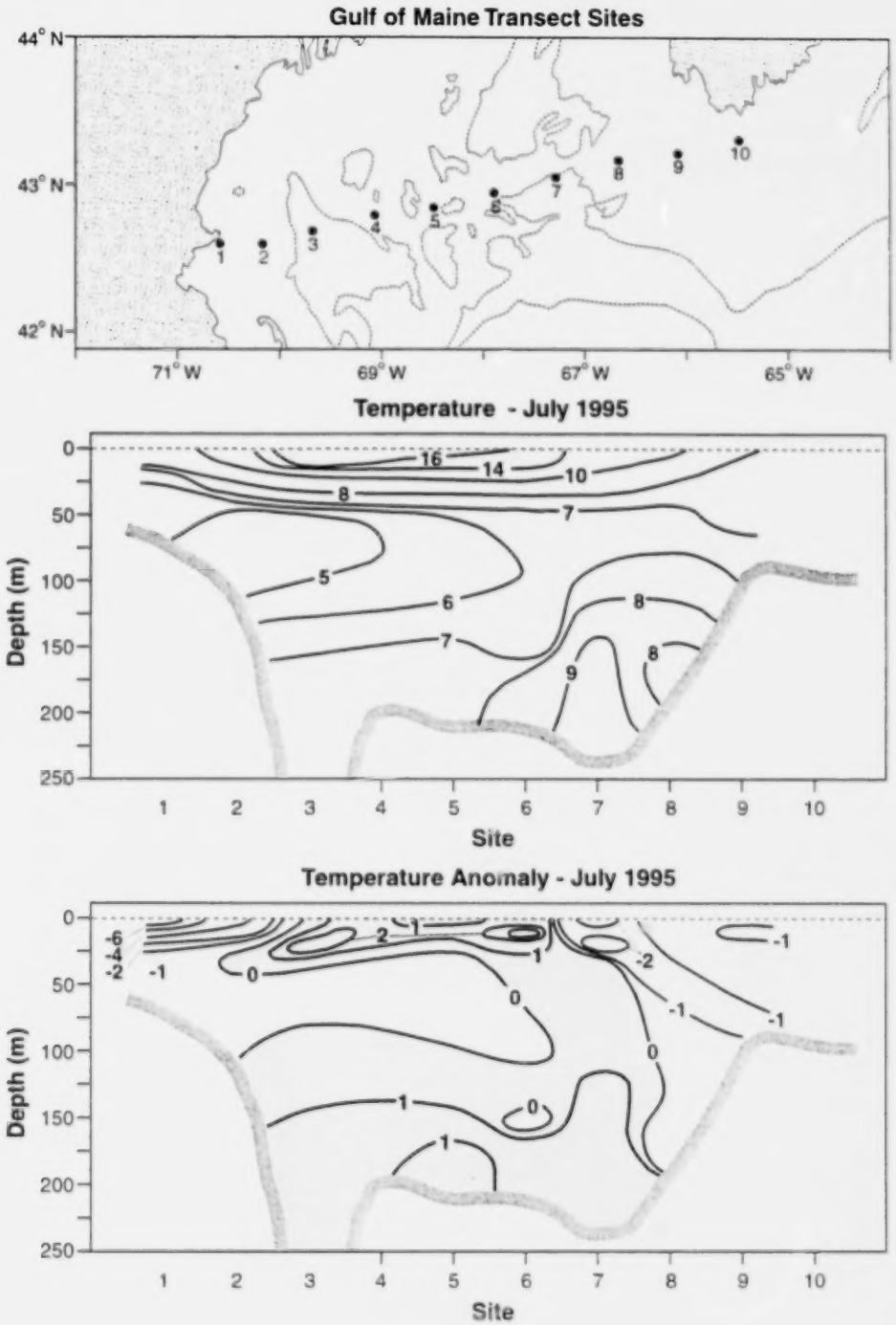


Fig. 7. The temperature (middle) and temperature anomalies (bottom) in degrees Celsius along a XBT transect (top) across the Gulf of Maine during July 1995.

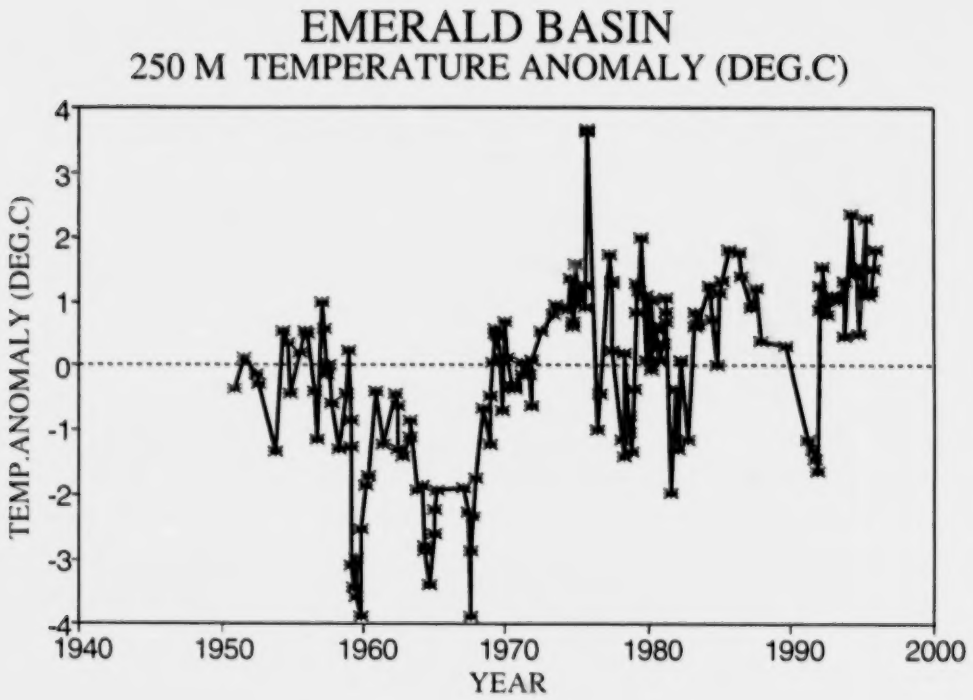
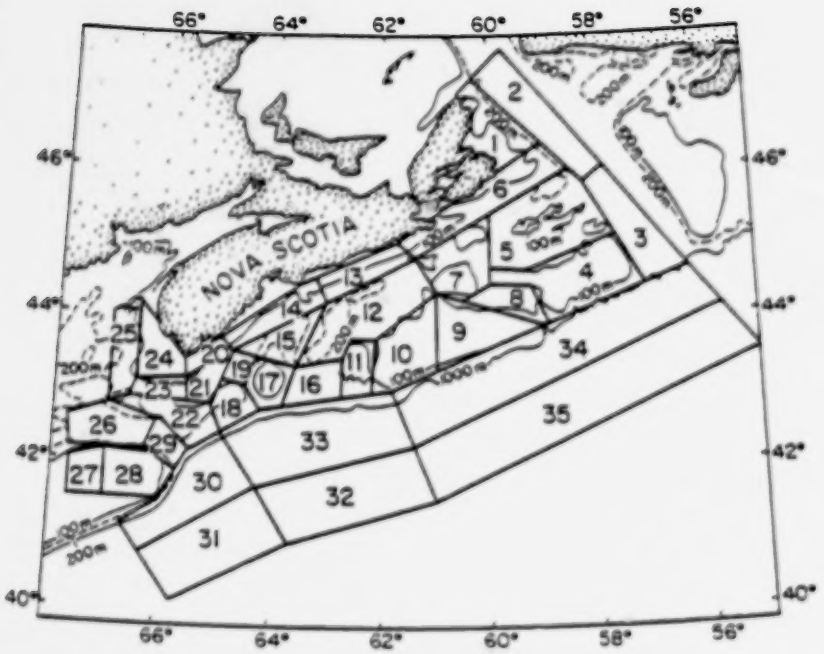


Fig. 8. Temperature anomalies (relative to 1961-90) at 250 m in Emerald Basin.



1. SYDNEY BIGHT
2. N. LAURENTIAN CHANNEL
3. S. LAURENTIAN CHANNEL
4. BANQUEREAU
5. MISAINE BANK
6. CANSO
7. MIDDLE BANK
8. THE GULLY
9. SABLE ISLAND
10. WESTERN BANK
11. EMERALD BANK
12. EMERALD BASIN
13. EASTERN SHORE
14. SOUTH SHORE
15. LAHAVE BASIN
16. SADDLE
17. LAHAVE BANK
18. BACCARO BANK
19. ROSEWAY BANK
20. SHELBURNE
21. ROSEWAY BASIN
22. BROWNS BANK
23. ROSEWAY CHANNEL
24. LURCHER SHOALS
25. E. GULF OF MAINE
26. GEORGES BASIN
27. GEORGES SHOAL
28. E. GEORGES BANK
29. N.E. CHANNEL
30. SOUTHERN SLOPE
31. SOUTHERN OFFSHORE
32. CENTRAL OFFSHORE
33. CENTRAL SLOPE
34. NORTHERN SLOPE
35. NORTHERN OFFSHORE

Fig. 9. The areas in which monthly means of temperature were estimated by Drinkwater and Trites (1987).

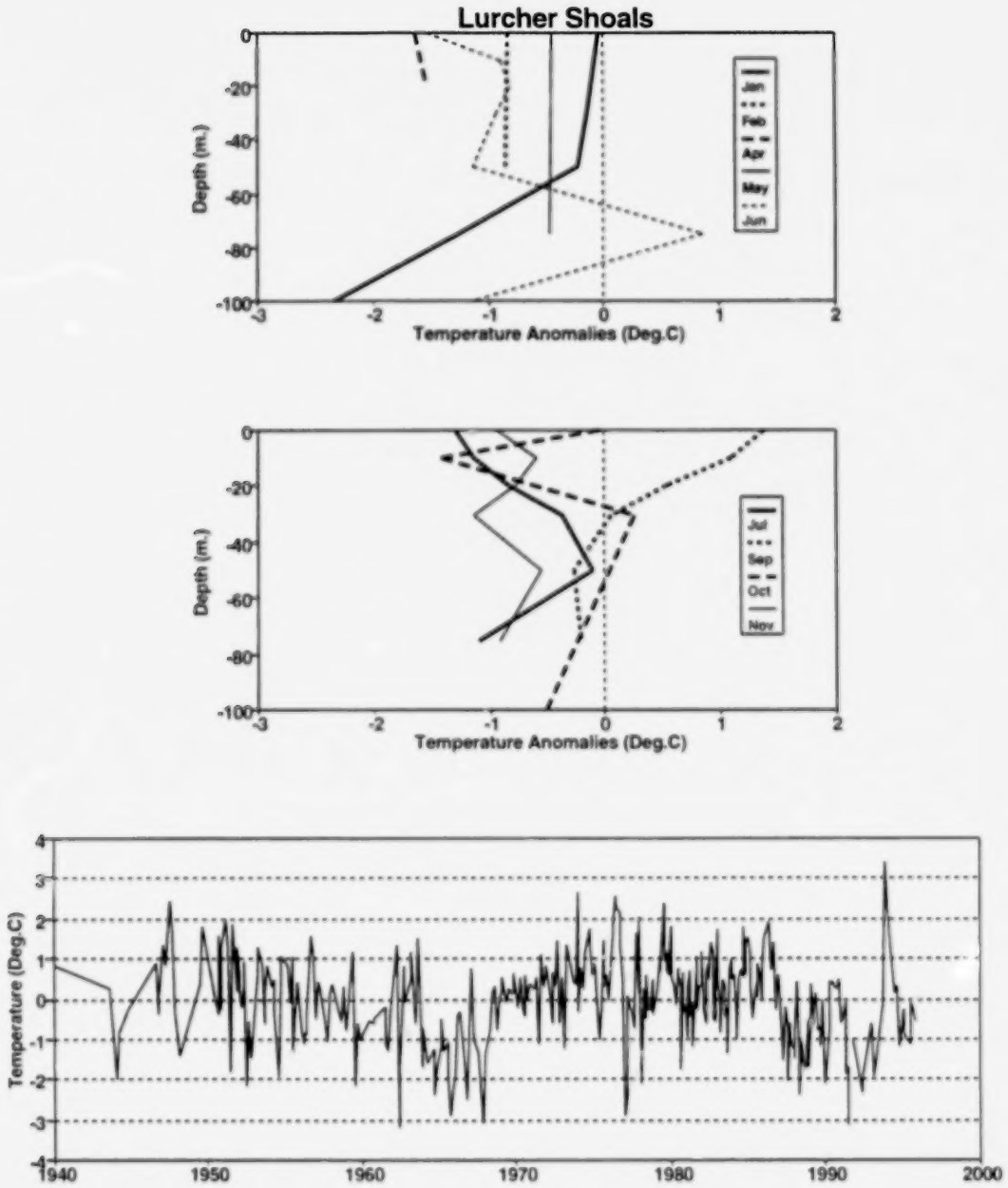


Fig. 10. The 1995 monthly temperature anomaly profiles (top) and temperature anomaly time series at 50 m (bottom) for Lurcher Shoals (area 24 in Fig. 9).

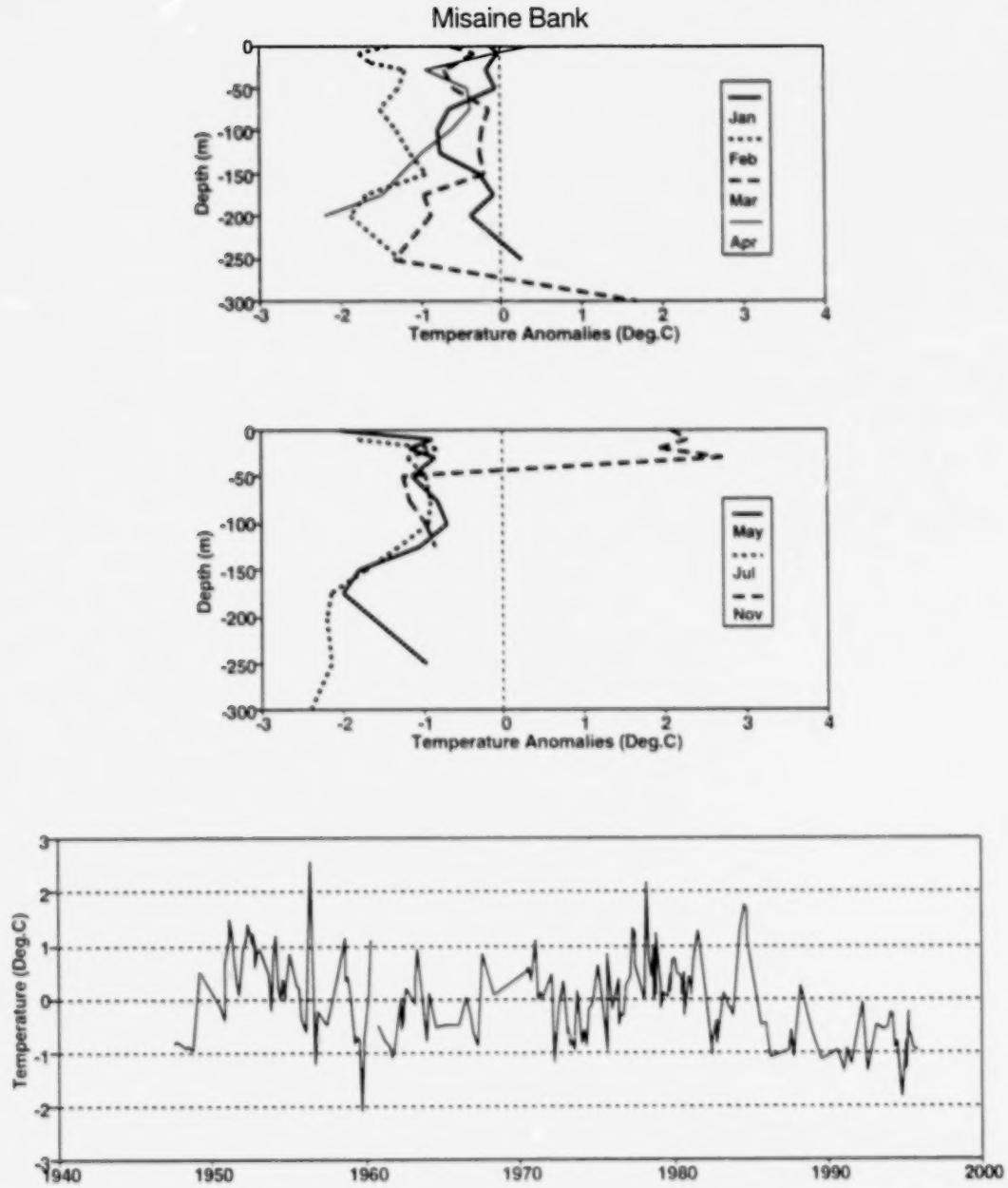


Fig. 11. The 1995 monthly temperature anomaly profiles (top) and temperature anomaly time series at 100 m (bottom) for Misaine Bank (area 5 in Fig. 9).

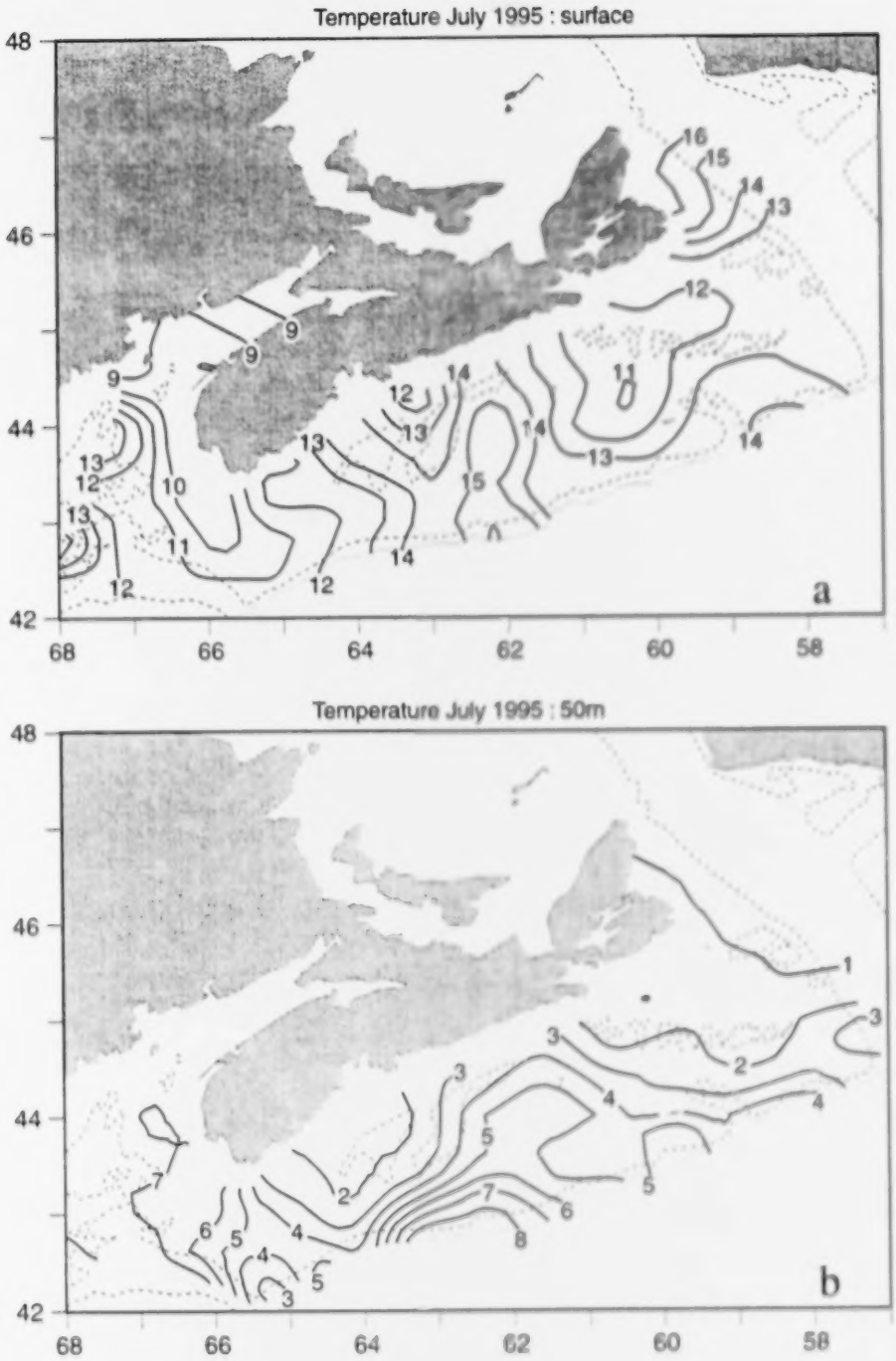


Fig. 12. Contours of optimally estimated temperatures at the surface (a) and 50m (b) during the 1995 July groundfish survey.

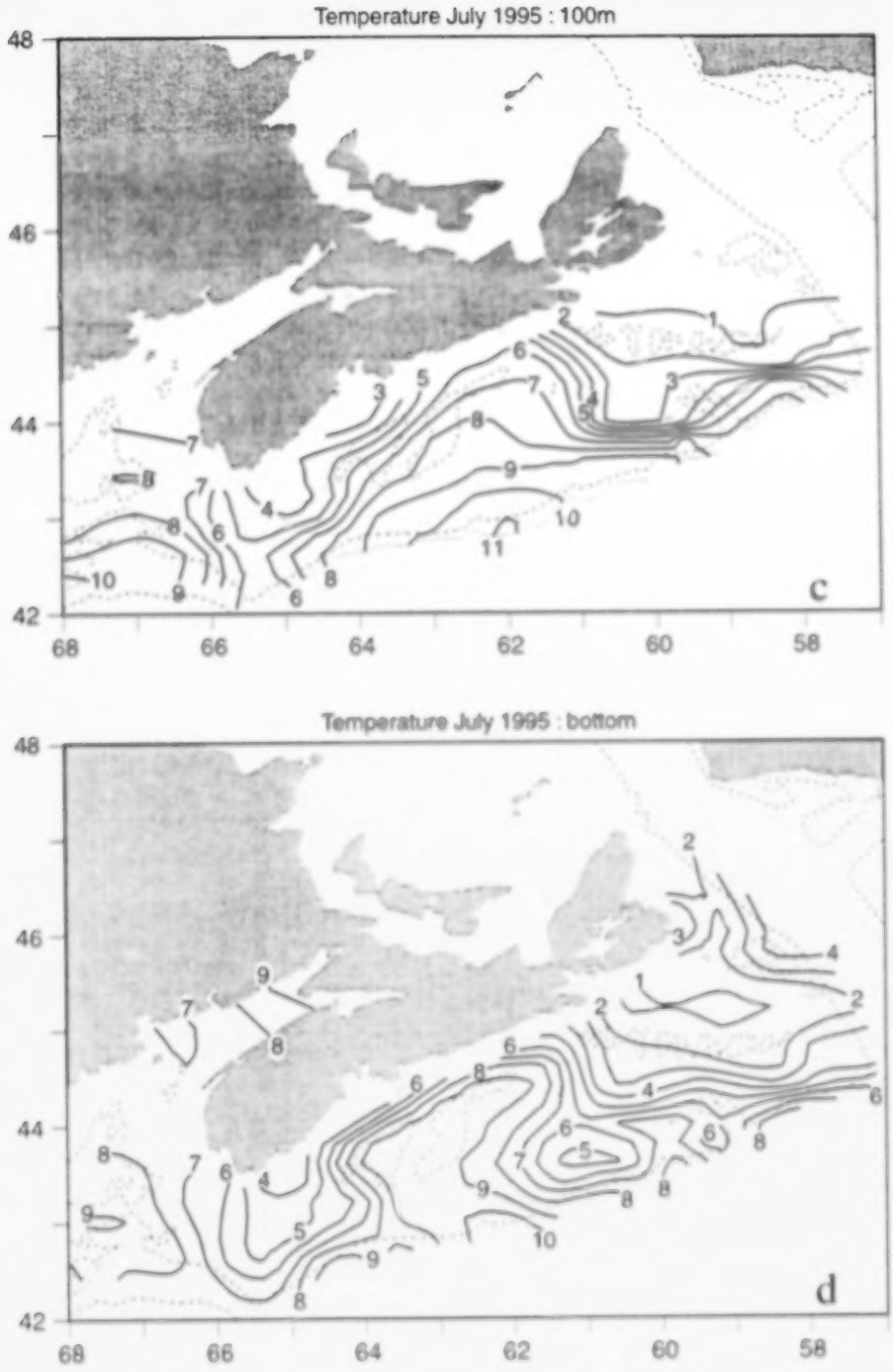


Fig. 12cont'd. Contours of optimally estimated temperatures at 100m (c) and near bottom (d) during the 1995 July groundfish survey.

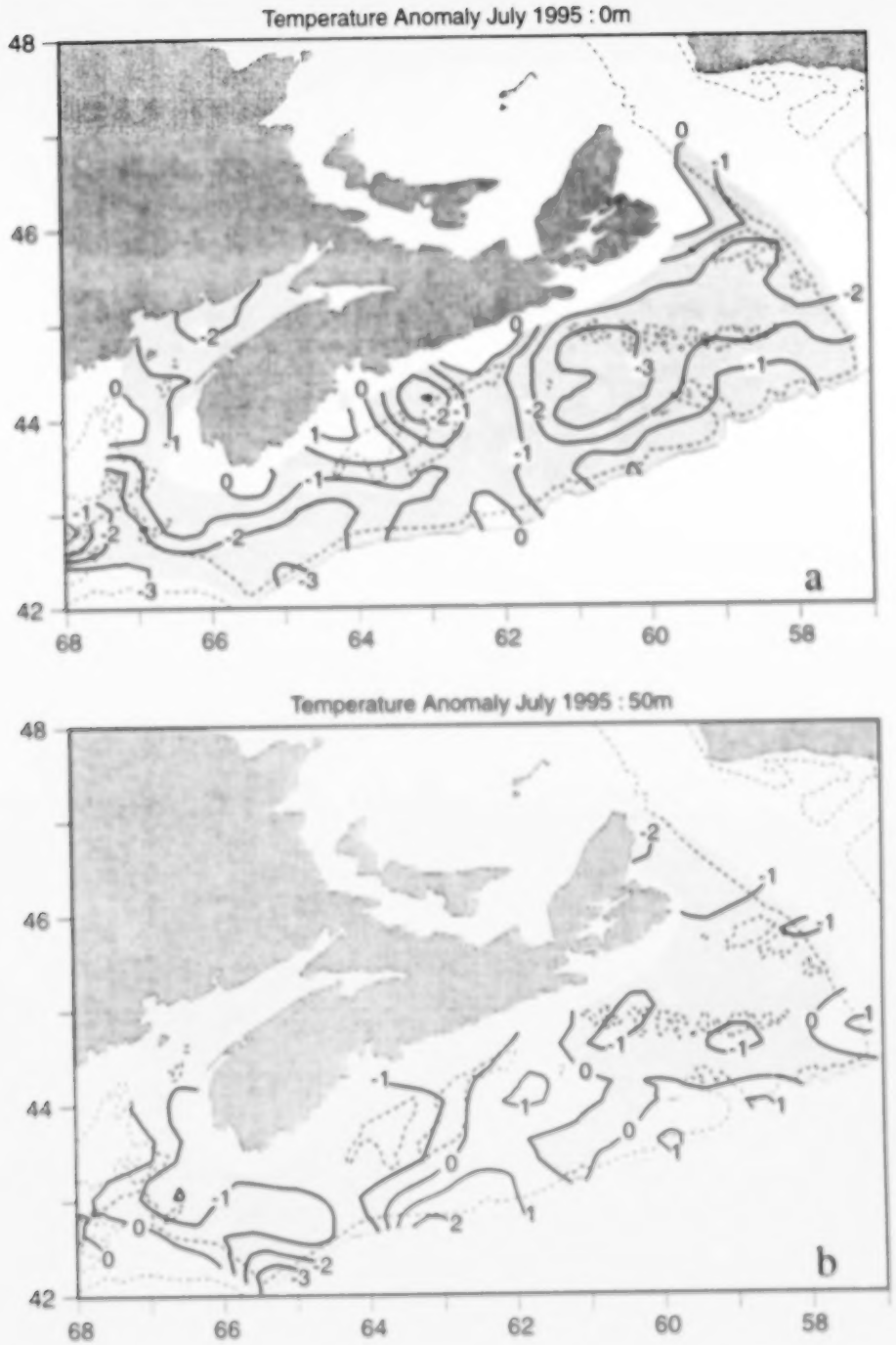


Fig. 13. Contours of optimally estimated temperature anomalies at the surface (a) and 50m (b) during the 1995 July groundfish survey.

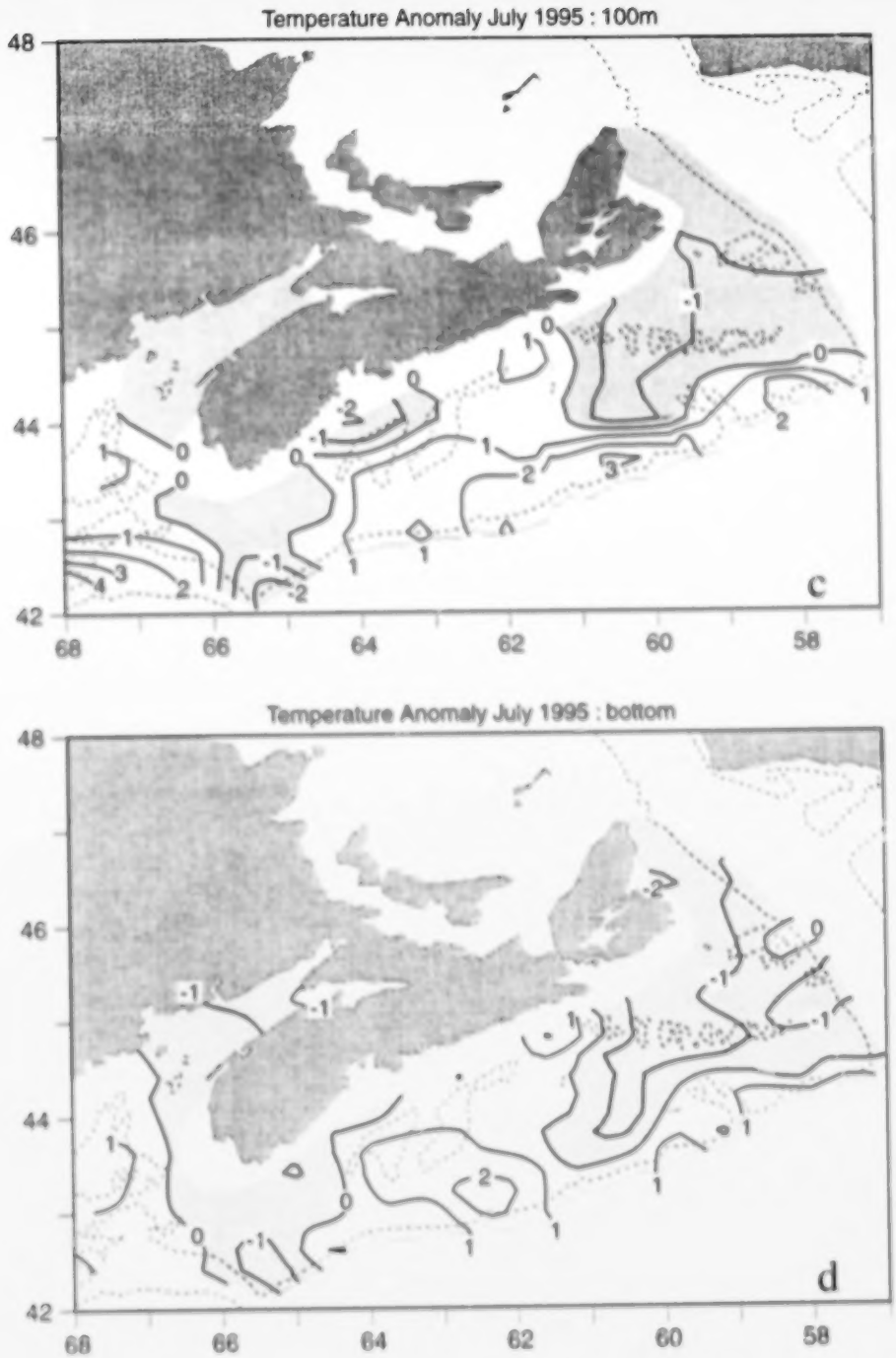


Fig. 13cont'd. Contours of optimally estimated temperature anomalies at 100m (c) and near bottom (d) during the 1995 July groundfish survey.

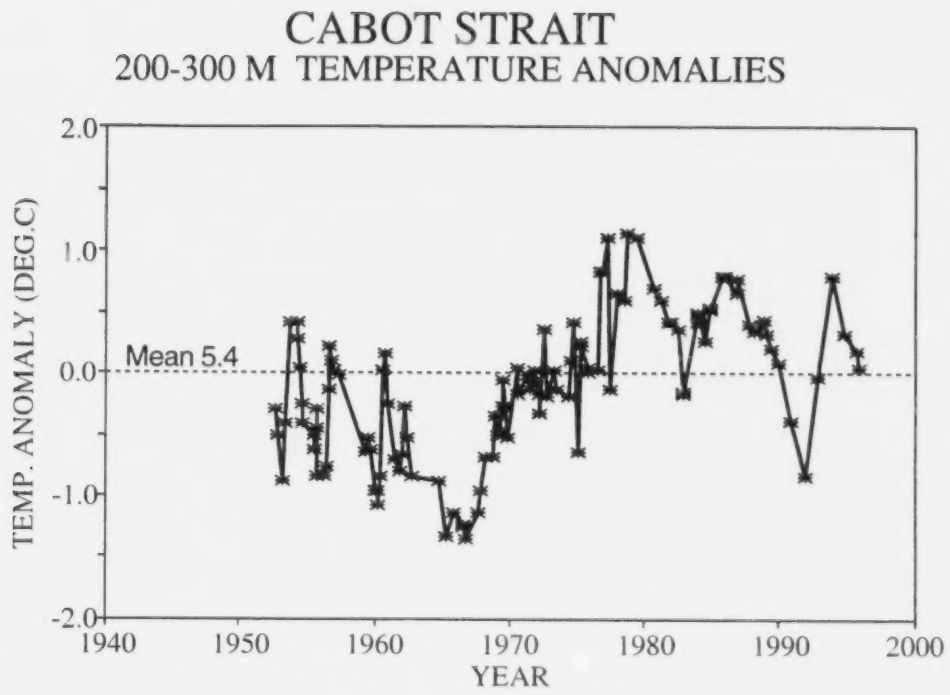


Fig. 14. Temperature anomalies (relative to 1961-90) for 200-300 m in Cabot Strait.